Claims

What is claimed is:

1. A projectile navigation, guidance, and control method comprising:

(a) repeatedly calculating position and attitude of a navigation solution for a host projectile using a state estimator, wherein said calculating utilizes a current parameter vector of said host projectile and previously calculated position and attitude of said navigation solution;

(b) receiving primary aiding data from a solid state navigational sensor (SSNS) module comprising at least one solid state navigational sensor;

(c) updating said position and attitude of said navigation solution based upon newly received primary aiding data received from said SSNS module; and

(d) communicating each of said repeatedly calculated navigation solutions to an external guidance and control processor adapted to provide real time navigation of said host projectile based upon said navigation solution.

2. The method according to claim 1, wherein said state estimator comprises a Bayesian state estimator.

3. The method according to claim 1, wherein said state estimator comprises a set of Kalman filters.

4. The method according to claim 1, wherein said state estimator comprises a set of extended Kalman filters.

5. The method according to claim 1, wherein said at least one solid state navigational sensor comprises an optical imaging sensor.

6. The method according to claim 1, wherein said at least one solid state navigational sensor comprises a non-imaging sensor.

7. The method according to claim 1, wherein said at least one solid state navigational sensor comprises a satellite based position-determining (SBPD) sensor.

8. The method according to claim 1, wherein said at least one solid state navigational sensor is selected from a group of optical imaging sensors consisting of an infrared sensor, visible light camera, sun sensor, and a star sensor.

9. The method according to claim 1, wherein said at least one solid state navigational sensor is selected from a group of non-imaging sensors consisting of a fiber optic gyroscope (FOG), magnetic field sensor, and a barometric pressure sensor.

10. The method according to claim 1, wherein said at least one solid state navigational sensor is selected from a group of satellite based position-determining (SBPD) sensors consisting of a global positioning system (GPS), global orbiting navigation system (GLONASS), and a Galileo navigation system.

11. The method according to claim 1, wherein said solid state navigational sensor (SSNS) module comprises a plurality of solid state navigational sensors.

12. The method according to claim 1, wherein said solid state navigational sensor (SSNS) module comprises at least one optical imaging sensor and at least one non-imaging sensor.

13. The method according to claim 1, wherein said solid state navigational sensor (SSNS) module comprises at least one optical imaging sensor and at least one satellite based position-determining (SBPD) sensor.

14. The method according to claim 1, wherein said solid state navigational sensor (SSNS) module comprises a plurality of solid state sensors, wherein said updating operation (c) further comprises:

(c-1) serially updating said position and attitude parameters of said navigation solution based upon newly received primary aiding data received from said SSNS module.

15. The method according to claim 1, wherein said solid state navigational sensor (SSNS) module comprises a plurality of solid state sensors, wherein said updating operation (c) further comprises:

(c-1) synchronizing signal output from each of said plurality of solid state navigational sensors and then updating said position and attitude of said navigation solution based upon newly received and synchronized primary aiding data received from said SSNS module.

16. The method according to claim 1, said method further comprising: steering said host projectile to an intended target based upon said repeatedly calculated navigation solutions.

17. The method according to claim 1, wherein said position and attitude parameters of said navigation solution is calculated on a substantially continuous basis, and said updating operation (c) is performed on a periodic basis.

18. The method according to claim 1, wherein said state estimator comprises a set of Kalman filters, said calculating operation (a) further comprising:

(a-1) performing a linearization of a set of non-linear equations of motions of said host projectile around a nominal trajectory and converting said set of non-linear equations of motion into a set of linearized equations of motions that is solvable by said set of Kalman filter.

19. The method according to claim 1, wherein said updating operation (c) further comprises:

(c-1) updating in real time said current parameter vector of said host projectile to provide in-flight corrections to initial conditions of an initially predicted trajectory of said host projectile.

20. The method according to claim 19, said method further comprising:

estimating a new parameter vector using a parameter estimator comprising of a stabilization phase, a data collection phase, and a parameter estimation phase; and

updating said current parameter vector with said new parameter vector.

21. The method according to claim l, said method further comprising:

predicting an impact point of said host projectile using a null miss predictive proportional navigation (PPN) guidance algorithm; and

generating a control command that is communicated to the canards and/or fins of said host projectile, wherein said control command is generated by comparing said predicted impact point with an aimpoint.

22. The method according to claim 1, said method further comprising:

calculating correction velocity, ΔV, required to navigate said host projectile to an aimpoint by applying a projected deficit velocity algorithm to projectile velocity, wherein said correction velocity, ΔV, is generated by aerodynamic forces on control surfaces of said host projectile.

23. The method according to claim 1, wherein said at least one solid state navigational sensor includes a multi-turn, fiber-optic coil adapted to provide two counter rotating, optical waves travelling in opposite directions through said multi-turn fiber-optic coil, wherein a phase difference between said two counter rotating, optical waves is used to calculate and update said attitude of said navigation solution.

24. The method according to claim 1, wherein said navigation solution further includes an altitude parameter, wherein said at least one solid state navigational sensor includes a barometric pressure transducer adapted to provide barometric pressure information, wherein said barometric pressure information is used to calculate and update altitude of said navigation solution.

25. The method according to claim 1, wherein said at least one solid state navigational sensor includes a magnetic field sensor adapted to provide a reference axis of said host projectile, wherein an angle between said reference axis and the local earth magnetic field vector is used to calculate and update a heading parameter of said navigation solution.

26. The method according to claim 1, wherein said at least one solid state navigational sensor includes a magnetometer sensor adapted to provide a magnetic field strength around said host projectile, wherein said magnetic field strength is compared to a pre-stored map of the local magnetic field strength to determine and update said position of said navigation solution.

27. The method according to claim 1, wherein said at least one solid state navigational sensor includes a sun sensor adapted to provide relative attitude angles of said host projectile and a solar disk using a position of a patch of sunlight passing through an entrance aperture of said sun sensor, wherein said relative attitude angles is used to calculate and update said attitude of said navigation solution.

28. The method according to claim 1, wherein said at least one solid state navigational sensor includes a star sensor adapted to provide a magnitude of brightness of one or more stars collected on a focal plane of said star sensor, wherein said magnitude of brightness is compared to a pre-stored star catalog to identify which particular star has been sighted, wherein an attitude angle of said host projectile is calculated based upon said star identification, and wherein said attitude angle is used to update said attitude of said navigation solution.

29. The method according to claim 1, wherein said at least one solid state navigational sensor includes infrared and visible light sensors adapted to provide images of nearby terrain, wherein received images of said terrain are compared to a pre-stored terrain map to determine a position of said host projectile, wherein said position of said host projectile is used to update said position of said navigation solution.

30. The method according to claim 1, wherein said navigation solution further comprises velocity of said host projectile, and wherein said calculating operation (a) further comprises repeatedly calculating said velocity of said navigation solution using said state estimator, wherein said calculating utilizes said current parameter vector of said host projectile and previously calculated position, velocity, and attitude of said navigation solution.

31. The method according to claim 30, wherein position and velocity of said host projectile is determined by at least one ground-based radar unit, wherein said position and velocity is uploaded to said host projectile and used to update said position and velocity of said navigation solution.

32. The method according to claim 1, wherein said host projectile is a non-thrusted flight vehicle.

33. The method according to claim 1, wherein said host projectile is a thrusted flight vehicle.

34. The method according to claim 1, wherein said calculating operation (a) further comprises:

utilizing body dynamics of said host projectile in addition to said primary aiding data to measure incremental changes in velocity and rotation angles of said host projectile.

35. The method according to claim 1, wherein said updating operation (c) further comprises:

(c-l) obtaining said primary aiding data from said solid state navigational sensor (SSNS) module at a medium clock rate;

(c-2) using a measurement model to convert said primary aiding data into a set of navigational measurements;

(c-3) performing a reasonableness test on said set of navigational measurements to find a suitable set of said navigational measurements;

(c-4) obtaining a high clock rate navigation solution by updating and propagating said state estimator with said suitable set of navigational measurements;

(c-5) transferring said high clock rate navigational solution to said parameter estimator and to an internal guidance and control module (IGCM); and

(c-6) providing said high clock rate navigational solution to said measurement model as a feedback signal.

36. The method according to claim 1, wherein said updating operation (c) further comprises:

(c-l) obtaining said primary aiding data from said solid state navigational sensor (SSNS) module at a medium clock rate;

(c-2) using a measurement model to convert said primary aiding data into a 6 degrees of freedom (DOF) solution;

(c-3) performing a reasonableness test on said 6 DOF solution to find a suitable 6 DOF solution;

(c-4) obtaining a high clock rate navigation solution by updating and propagating said state estimator with said suitable 6 DOF solution;

(c-5) transferring said high clock rate navigational solution to said parameter estimator and to an internal guidance and control module (IGCM); and

(c-6) providing said high clock rate navigational solution to said measurement model as a feedback signal.

37. The method according to claim 1, wherein said communicating operation (d) further comprises:

(d-1) receiving said high clock rate navigation solution from said state estimator;

(d-2) receiving current control surface deflections data from an external guidance and control processor (EGCP);

(d-3) receiving said medium clock rate primary aiding data from said solid-state navigation system (SSNS) module;

(d-4) initializing an optimization procedure for determining an optimized performance index;

(d-5) generating an optimal parameter vector of said host projectile using data obtained in operations (d-1), (d-2), (d-3), and (d-4);

(d-6) updating said current parameter vector with said optimal parameter vector;

(d-7) communicating said current parameter vector to said state estimator, said measurement module, and said internal guidance and control module (IGCM); and

(d-8) generating an optimal trajectory to be used as a nominal trajectory by said state estimator using said current parameter vector.

38. The method according to claim 37, wherein said generating operation (d-5) further comprises:

(d-5-1) generating a set of trial parameter vectors using perturbations of said parameter vector calculated by said optimization procedure;

(d-5-2) generating a set of trial trajectories using said set of trial parameter vectors;

(d-5-3) calculating a set of performance indexes by comparing said set of trial trajectories with a measured trajectory formed by said navigation solution; and

(d-5-4) searching and identifying an optimum parameter vector that minimizes said performance index.

39. A projectile navigation, guidance, and control system comprising:

a state estimator adapted to repeatedly calculate position and attitude of a navigation solution for a host projectile utilizing a current parameter vector of said host projectile and previously calculated position and attitude of said navigation solution;

a solid state navigational sensor (SSNS) module adapted to provide primary aiding data in response to signals received from at least one solid state navigational sensor configured with said SSNS module, wherein said position and attitude of said navigation solution are updated based upon newly received primary aiding data received from said SSNS module; and

an external guidance and control processor adapted to generate a guidance and control signal based upon each of said calculated navigation solutions, wherein said guidance and control signal is adapted to provide real time navigation of said host projectile.

40. The system according to claim 39, wherein said state estimator comprises a Bayesian state estimator.

41. The system according to claim 39, wherein said state estimator comprises a set of Kalman filters.

42. The system according to claim 39, wherein said state estimator comprises a set of extended Kalman filters.

43. The system according to claim 39, wherein said at least one solid state navigational sensor comprises an optical imaging sensor.

44. The system according to claim 39, wherein said at least one solid state navigational sensor comprises a non-imaging sensor.

45. The system according to claim 39, wherein said at least one solid state navigational sensor comprises a satellite based position-determining (SBPD) sensor.

46. The system according to claim 39, wherein said solid state navigational sensor (SSNS) module comprises a plurality of solid state navigational sensors.

47. The system according to claim 39, wherein said solid state navigational sensor (SSNS) module comprises at least one at least one non-imaging sensor and at least one satellite based position-determining (SBPD) sensor.

48. The system according to claim 39, wherein said at least one solid state navigational sensor includes a multi-turn, fiber-optic coil adapted to provide two counter rotating, optical waves travelling in opposite directions through said multi-turn fiber-optic coil, wherein a phase difference between said two counter rotating, optical waves is used to calculate and update said attitude of said navigation solution.

49. The system according to claim 39, wherein said navigation solution further includes an altitude parameter, and wherein said at least one solid state navigational sensor includes a barometric pressure transducer adapted to provide barometric pressure information, wherein said barometric pressure information is used to calculate and update altitude of said navigation solution.

50. The system according to claim 39, wherein said at least one solid state navigational sensor includes a magnetic field sensor adapted to provide a reference axis of said host projectile, wherein an angle between said reference axis and the local earth magnetic field vector is used to calculate and update a heading parameter of said navigation solution.

51. The system according to claim 39, wherein said at least one solid state navigational sensor includes a magnetometer sensor adapted to provide a magnetic field strength around said host projectile, wherein said magnetic field strength is compared to a pre-stored map of the local magnetic field strength to determine and update said position said navigation solution.

52. The system according to claim 39, wherein said at least one solid state navigational sensor includes a sun sensor adapted to provide relative attitude angles of said host projectile and a solar disk using a position of a patch of sunlight passing through an entrance aperture of said sun sensor, wherein said relative attitude angles is used to calculate and update said attitude of said navigation solution.

53. The system according to claim 39, wherein said at least one solid state navigational sensor includes a star sensor adapted to provide a magnitude of brightness of one or more stars collected on a focal plane of said star sensor, wherein said magnitude of brightness is compared to a pre-stored star catalog to identify which particular star has been sighted, wherein an attitude angle of said host projectile is calculated based upon said star identification, and wherein said attitude angle is used to update said attitude of said navigation solution.

54. The system according to claim 39, wherein said at least one solid state navigational sensor includes infrared and visible light sensors adapted to provide images of nearby terrain, wherein received images of said terrain are compared to a pre-stored terrain map to determine a position of said host projectile, wherein said position of said host projectile is used to update said position of said navigation solution.

55. The system according to claim 39, wherein said navigation solution further comprises velocity of said host projectile, and wherein said calculating operation further comprises repeatedly calculating said velocity of said navigation solution using said state estimator, wherein said calculating utilizes said current parameter vector of said host projectile and previously calculated position, velocity, and attitude of said navigation solution.

56. The system according to claim 55, wherein position and velocity of said host projectile is determined by at least one ground-based radar unit, wherein said position and velocity is uploaded to said host projectile and used to update said position and velocity of said navigation solution.

57. The system according to claim 39, wherein said host projectile is a non-thrusted flight vehicle.

58. The system according to claim 39, wherein said host projectile is a thrusted flight vehicle.